United Kingdom Atomic Energy Authority

AWRE, Aldermaston

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Some Seismic Results of the CANNIKIN Underground Explosion at Amchitka, Aleutian Islands

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SUMMARY

CANNIKIN was a large nuclear explosion (said to be 5 megatons), fired underground on Amchitka in the Aleutian Islands, Alaska. The detonation occurred on 6 November 1971 and the cavity it created collapsed on 8 November 1971. Because the explosion is one of the largest to take place underground, and recordings were made over an unusually wide band of the seismic spectrum, the events are of special interest. This report gives the basic seismic data from these events, recorded by a UKAEA R and D facility at Wolverton (WOL) in southern England, a temporary UKAEA recorder on Ascension Island (AI), the Hagfors (HFS) long period array in Sweden and the 4 UKAEA type arrays.

1. INTRODUCTION

Amchitka, one of the Aleutian Islands, has been the site of 3 underground nuclear explosions:-

LONGSHOT [1]	29 October 1965	80 kton	Press reports
MILROW [2]	2 October 1969	about 1 Mton)	
CANNIKIN	6 November 1971	about 5 Mton)	

This report gives the data on the third and largest of the series and the seismic waves generated by the collapse on 8 November 1971. CANNIKIN was fired at a point to the north-east of the previous two explosions (figure 13).

The stations used in recording the data presented in this report are:-

(1) Short period systems:-

Eskdalemuir [3]	Scotland (EKA)	55° 19' 59.0"N	3° 09' 33.0"W
Yellowknife [3]	Canada (YKA)	62° 29' 34.3"N	114° 36' 16.5"W
Warramunga [3]	Australia (WRA)	19° 56' 52.0"S	134° 21' 03.0"E
Gauribidanur [3]	India (GBA)	13° 36' 15.0"N	77° 26' 10.0"E
Wolverton	England (WOL)	51° 19' 00.0"N	1° 03' 00.0"W

(2) Long period instruments were at:-

Eskdalemuir	Vault	55° 20' 02.0"N	3° 11' 20.0"W
Yellowknife	Local site	62° 28' 42.0"N	114° 28' 42.0"W
Gauribidanur	Red Arm	13° 42' 37.0"N	77° 15' 32.0"E
Wolverton	England (WOL)	51° 19' 00.0"N	1° 03' 00.0"W
Ascension Island	(AI)	7° 55' 46.8"S	14° 24' 46.2"W
Hagfors [4]	Sweden (HFS)	60° 08' 03.0"N	13° 41' 44.0"E

The relative positions of these stations are shown in an equidistant azimuthal great circle map, centred on Amchitka (figure 14).

The long period instruments are:-

Yellowknife (YKA) Geotech SL210
Eskdalemuir (EKA) UKAEA VS1

Gauribidanur (GBA))
Wolverton (WOL)) Geotech S11 (7505A)
Hagfors (HFS))

Ascension Island (AI) Modified Sprengnether

The responses of these long period systems are given in figures 16 to 22. The short period records, with the exception of Wolverton (WOL), are from Willmore Mark II seismometers. At Wolverton the long period, simulated Kirnos and short period seismograms were derived from one long period instrument [5].

Table 1 [6] gives distance, azimuth and back bearing for the stations used from the CANNIKIN epicentre.

TABLE 1

Station	Distance, Degrees	Back Bearing, Degrees	Azimuth, Degrees
YKA	36.1	283.7	46.2
HFS	68.1	9.8	352.2
EKA	73.6	358.5	1.3
WOL	77.6	359.8	0.2
WRA	81.2	26.5	222.1
GBA	86.6	37.9	287.5
AI	135.2	348.0	19.2

The source information for CANNIKIN is contained in table 6, and for COLLAPSE in table 8.

2. RESULTS

2.1 Seismograms of CANNIKIN are shown in figures 1 to 9 and measurements from these are given in captions to the figures and in tables 4 and 7. Body wave magnitudes m_b were measured in the conventional way and surface wave magnitudes M_s were estimated using the expression:-

$$M_s = \log A + B'(\Delta) + P(T), \qquad [7]$$

where $B'(\Delta)$ is a distance term and $P(T)$ is a transmission path term. In estimating the $P(T)$ term, the path to YKA was assigned a "North American" path and to GBA a "Eurasian" path. Paths to the other stations were given "Mixed" path corrections (see reference [7]).

The magnitude results for CANNIKIN are summarised in table 2. Note that the average surface wave magnitude is 5.75 which, using the magnitude/yield relationship $M_s = \log Y + 2.0$ of Marshall et al. [8], implies a yield of 5.6 Mton, in good agreement with press reports, but note that the Atomic Energy Commission of the USA estimates less than 5 megatons [9].

TABLE 2

CANNIKIN - Summary of Magnitude Results

Station	Short Period Body Waves		Long Period Body Waves		Long Period Surface Waves	
	Period, T, s	Magnitude, m_b	Period, T, s	Magnitude, m_b	Period, T, s	Magnitude, M_s
YKA	1.25	6.85†	3.2	7.08	19	6.02
HFS	*	*	23	4.93	23	5.66
EKA	0.80	6.96	16	4.97	21	5.69
			(Kir 2	7.62	NS	-
WOL	0.90	7.11	(W/B 10	6.15	27	5.69
			(N/B 19	5.02	NS	-
WRA	0.90	6.73	No long period seismometer			
GBA	0.95	Overloaded	20	4.98	20.5	5.56
AI	*	*	NS	NS	18.5	5.85

* No short period record.
† Derived from measurements provided by Earth Physics Branch, Ottawa.
NS Not seen.

The epicentre computed, using arrival times at the 4 arrays, is 51.62°N ± 0.81° 179.13°E ± 1.25°, with the Lilwall and Douglas travel times [10]. CANNIKIN surface wave magnitudes are given in table 4.

2.2 Seismograms of CANNIKIN COLLAPSE are shown in figures 10 and 11, and measurements from these are given in tables 5 and 9. The magnitude results for COLLAPSE are summarised in table 3. The average surface wave magnitude of COLLAPSE is 5.07 which is equivalent to a yield of less than one quarter of CANNIKIN. COLLAPSE surface wave magnitudes are given in table 5.

TABLE 3

CANNIKIN COLLAPSE

Summary of Magnitude Results

Station	Short Period Body Waves		Long Period Surface Waves	
	Period T, s	Magnitude, m_b	Period T, s	Magnitude, M_s
YKA	1.25	4.70	18	5.15
HFS	*	-	21	5.18
EKA	NS	-	20	4.92
WOL	NS	-	(W/B 26	5.11
			(N/B 26	4.92
WRA	NS	-	No long period seismometer	
GBA	0.85	4.36	19	5.10
AI	*	-	18	5.09

* No short period record.
NS Not seen.

Surface waves of CANNIKIN and COLLAPSE (at YKA) are compared (figure 12) to show that the surface waves from the COLLAPSE have the opposite polarity to the surface waves from CANNIKIN.

TABLE 4

CANNIKIN Surface Wave Results

Station	Distance, Degrees	Replay Gain, K	A_{max} ½ pk/pk, mμ	Period T, s	Magnitude, M_s
YKA	36.1	0.69	38200	19	6.02
HFS	68.1	3.62	3430	23	5.66
EKA	73.6	5.00	3320	21	5.69
WOL W/B	77.6	4.77	2580	27	5.69
GBA	86.6	9.11	2500	20.5	5.56
AI N/B	135.2	5.53	2985	18.5	5.85
				Average M_s	5.75

TABLE 5

COLLAPSE Surface Wave Results

Station	Distance, Degrees	Replay Gain, K	A_{max} ½ pk/pk, mμ	Period T, s	Magnitude, M_s
YKA	36.1	2.93	5180	18	5.15
HFS	68.1	7.73	1140	21	5.18
EKA	73.6	23.97	560	20	4.92
WOL W/B	77.6	12.35	680	26	5.11
WOL N/B		28.0	440	26	4.92
GBA	86.6	15.86	880	19	5.10
AI	135.2	30.0	500	18	5.09
				Average M_s	5.07

3. ACKNOWLEDGMENTS

The recordings at the overseas stations were made possible by the co-operation of the Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Canada; the Atomic Energy Establishment, Trombay, India; the Australian National University, Canberra, Australia; the Research Institute of National Defence, Stockholm, Sweden; and the Institute of Geological Sciences (NERC).

REFERENCES

1. P D Marshall, E W Carpenter, A Douglas and J B Young: "Some Seismic Results of the LONGSHOT Explosion". AWRE Report 067/66

2. P D Marshall, D J Corbishley and P G Gibbs: "Some Seismic Results of the MILROW Underground Nuclear Explosion". AWRE Report 047/70

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5. P D Marshall, R F Burch and A Douglas: "How and Why to Record Broad Band Seismic Signals". Nature, 239 (5 September 1972)

6. J B Young and P G Gibbs: "GEDESS: A Series of Computer Programs for Deriving Information at Selected Recording Sites for Signals from Known Hypocentres". AWRE Report 054/68

7. P D Marshall and P W Basham: "Discrimination between Earthquakes and Underground Explosions Employing an Improved M_S Scale". Geophys J Roy Astr Soc, 28, 5, 431-458 (1972)

8. P D Marshall, A Douglas and J A Hudson: "Surface Waves from Underground Explosions". Nature, 234, 5323, 8-9 (5 November 1971)

9. Annual Report to Congress of the Atomic Energy Commission for 1971, US Government (January 1972)

10. R C Lilwall and A Douglas: "Estimation of P-Wave Travel Times Using the Joint Epicentre Method". Geophys J Roy Astr Soc, 19, 2, 165-181 (1970)

11. Earthquake Data Report. United States Department of Commerce, NOAA, ERL, EDR No. 82-71 (8 December 1971)

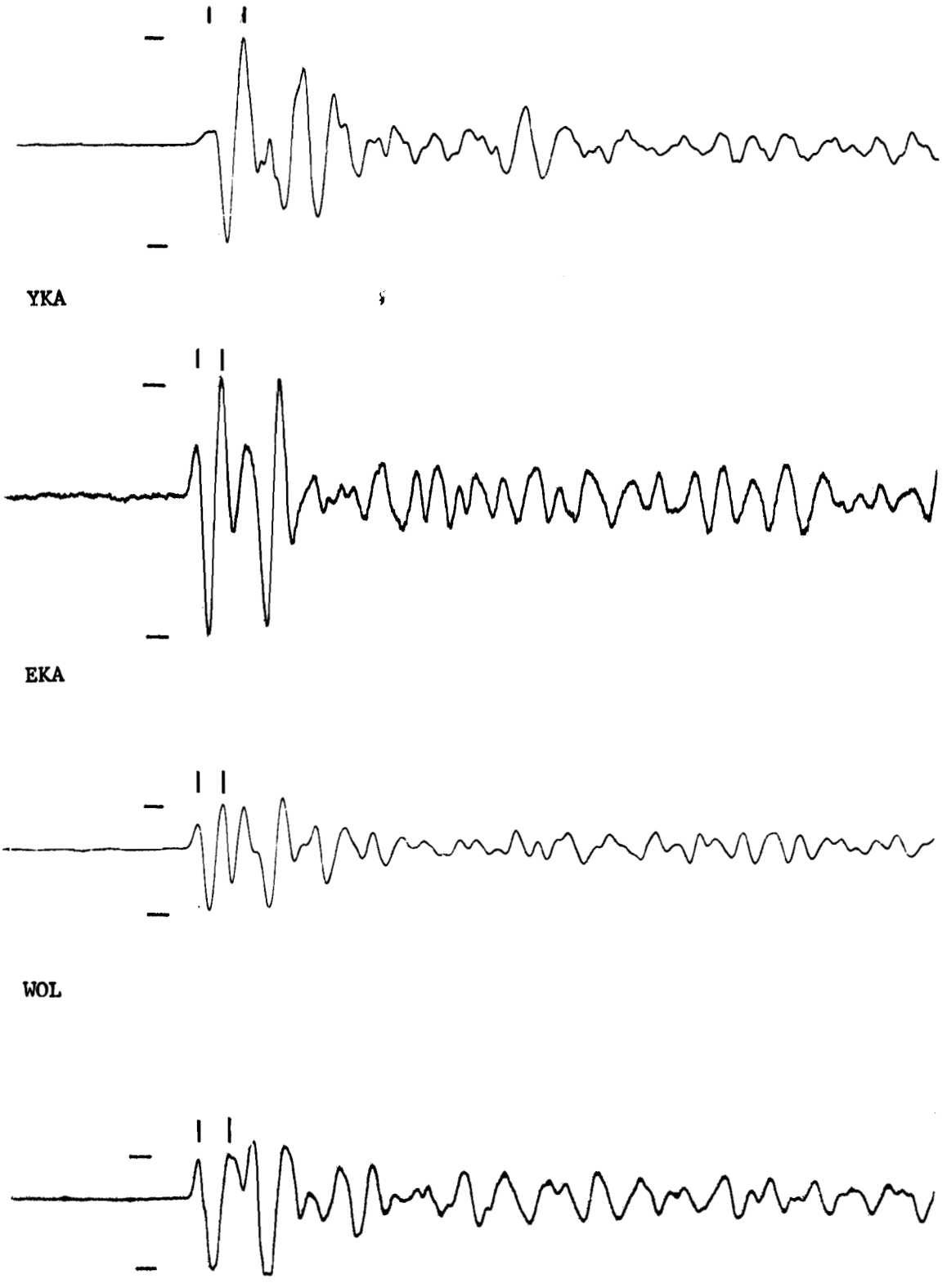


FIGURE 1. CANNIKIN. SHORT PERIOD BODY WAVES

TABLE 6

Code name		CANNIKIN [11]
Date		6 November 1971
Origin time		22 00 00.1 GMT
Site	Latitude Longitude	51° 28' 18.7"N 179° 06' 24.3"E
Depth, relative to ground zero		5876 ft (1791 m)
Geological medium		Basalt) From Press Reports
Yield		5 Mton)
Magnitude	m_b	6.8
	M_s	5.7

TABLE 7

Short Period Body Waves

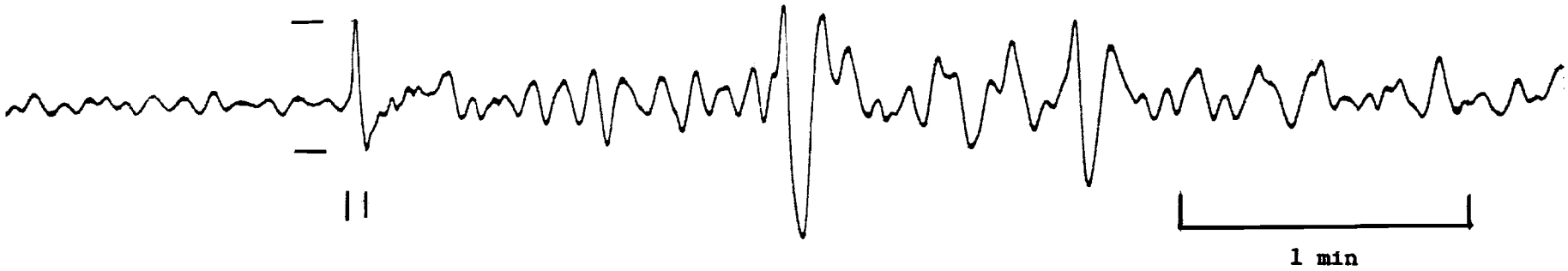
Station	Onset, h min s	O - C, s	Amplitude, mμ	Period T, s	Magnitude, m_b
YKA	22 07 01.0	- 3.7	2275	1.25*	6.85*
HFS	No Short	Period	Record	-	-
EKA	22 11 31.7	- 3.7	1050	0.80	6.96
WOL	22 11 54.9	- 3.6	1455	0.90	7.11
WRA	22 12 16.5	- 2.1	726	0.90	6.73
GBA	22 12 43.1	- 3.0	Overloaded	0.95	-
AI	No Short	Period	Record	-	-
			Average m_b		6.91

Computed onset time derived from Gedess (Reference [6]).

O = observed onset time.

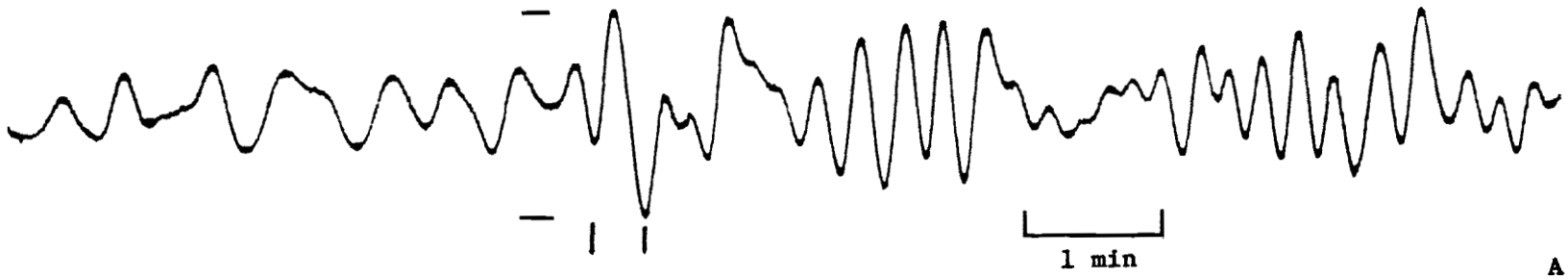
C = computed onset time.

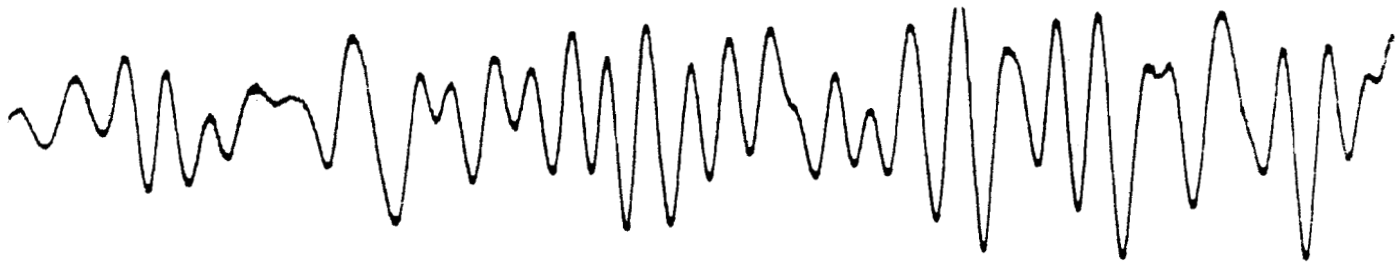
* Derived from measurements provided by Earth Physics Branch, Ottawa.



STATION	YKA
Gain (Replay)	1.06 K
Period, s	3.2
Amplitude, mμ	9810
Magnitude, m_b	7.08

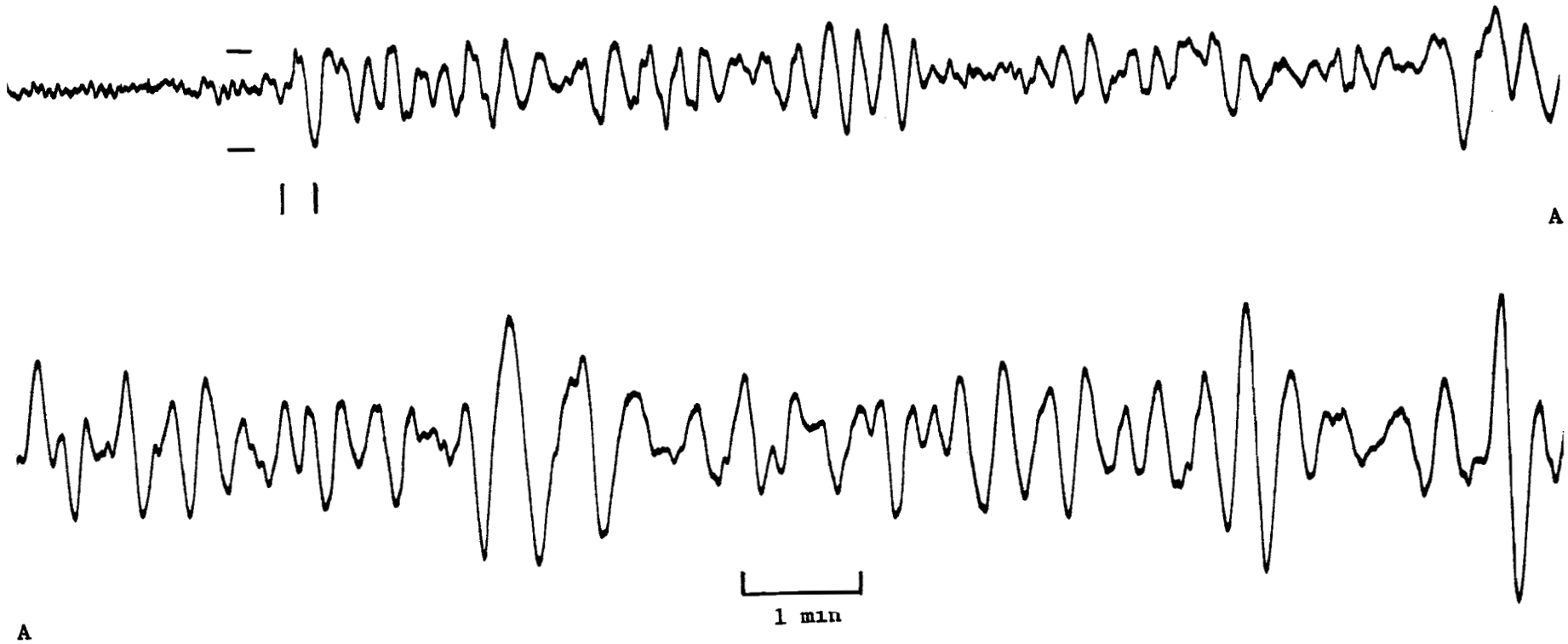
FIGURE 2. CANNIKIN. LONG PERIOD BODY WAVES (YKA)





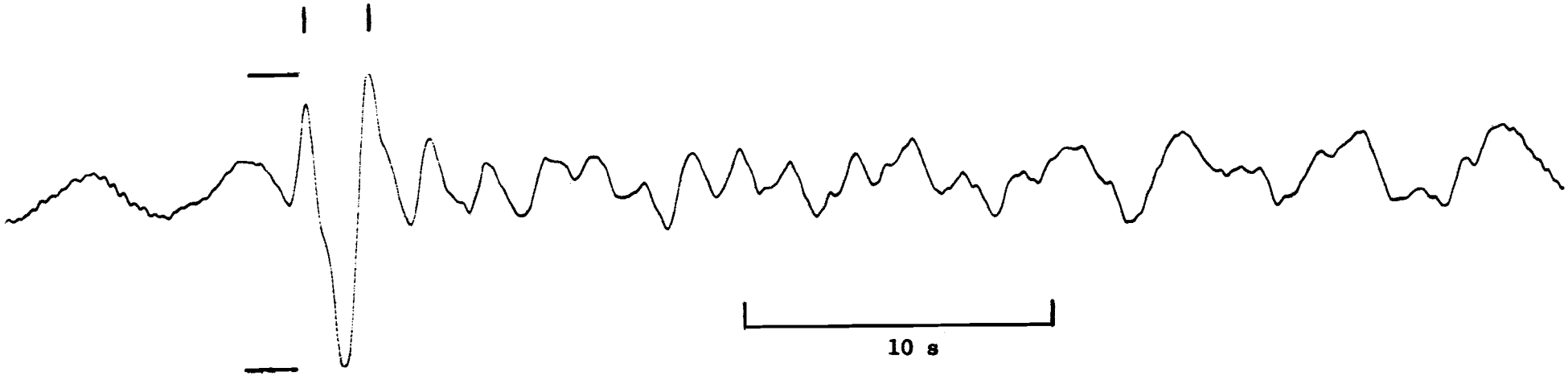
STATION	HFS
Gain (Replay)	73 K
Period, s	23
Amplitude, mμ	195
Magnitude, m_b	4.93

FIGURE 3. CANNIKIN. LONG PERIOD BODY WAVES (HFS)



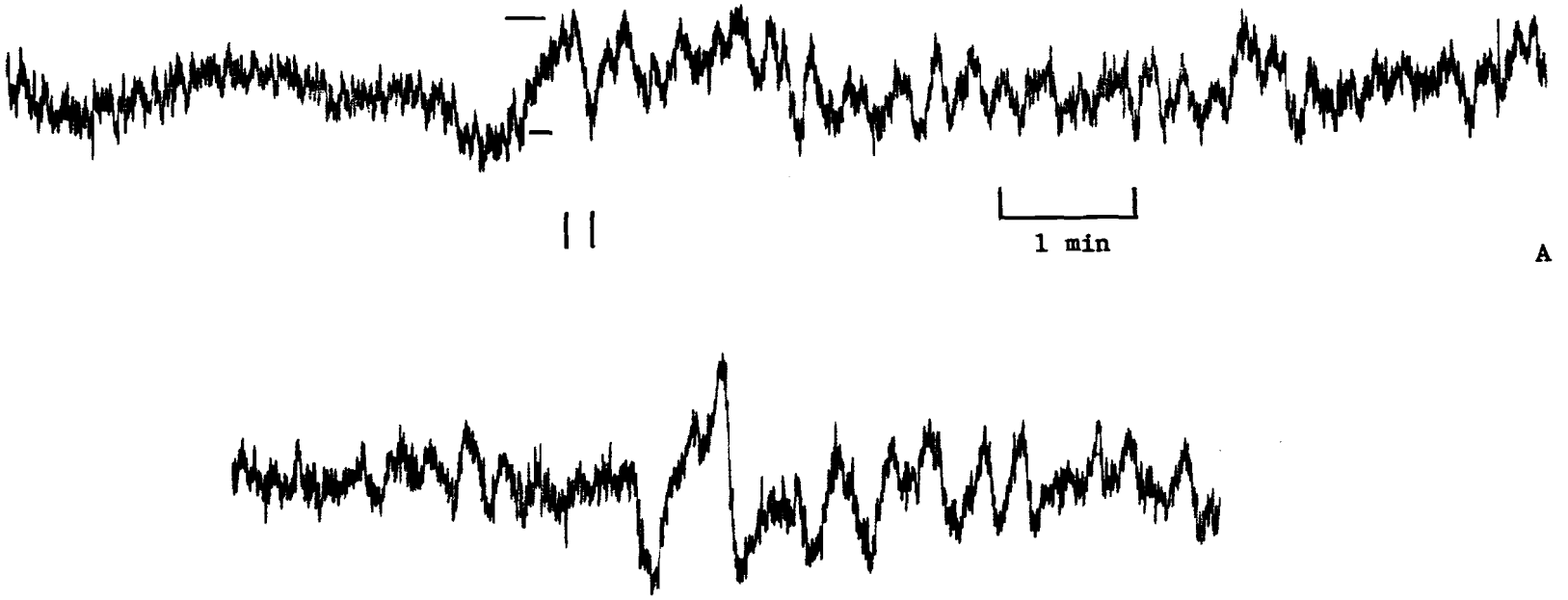
STATION	EKA
Gain (Replay)	36 K
Period, s	16
Amplitude, mμ	215
Magnitude, m_b	4.97

FIGURE 4. CANNIKIN. LONG PERIOD BODY WAVES (EKA)



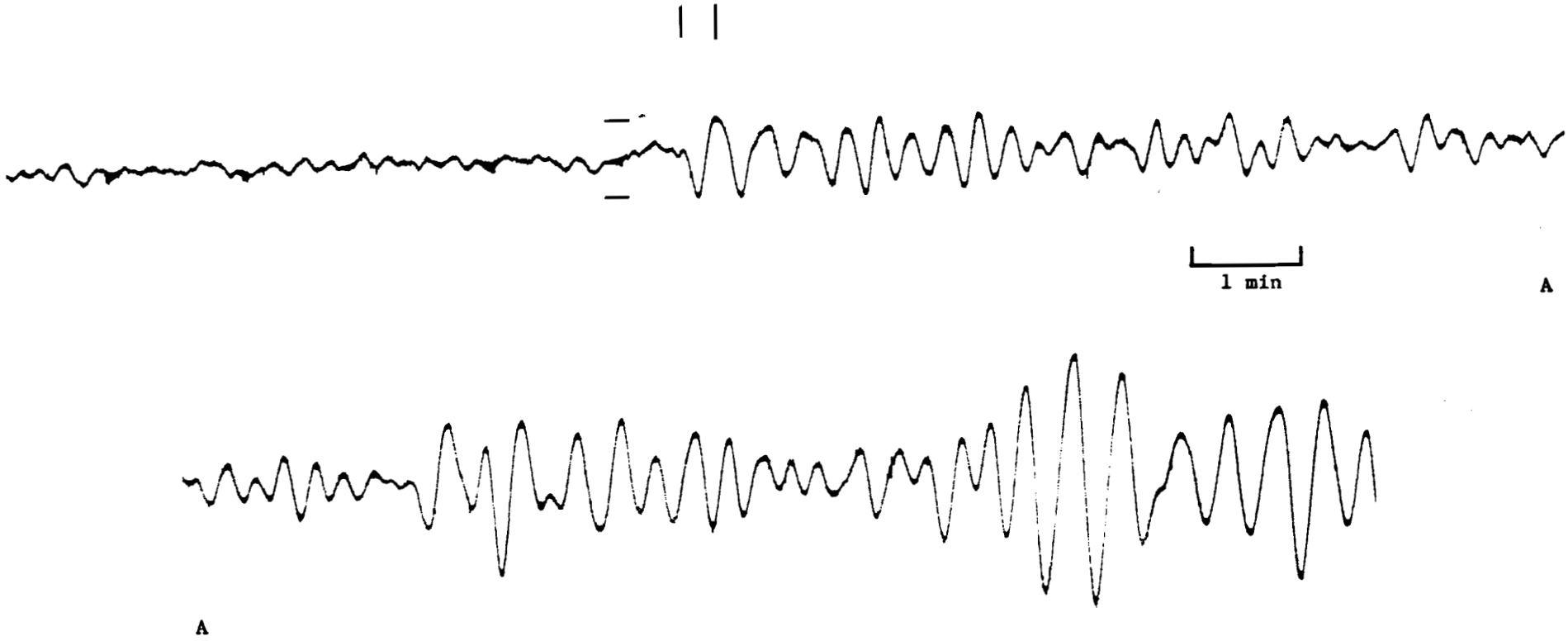
STATION	WOL
Simulated Kirnos	
Gain (Replay)	2.2 K
Period, s	2.1
Amplitude, m_μ	11135
Magnitude, m_b	7.62

FIGURE 5. CANNIKIN. LONG PERIOD BODY WAVES (WOL - Kirnos)



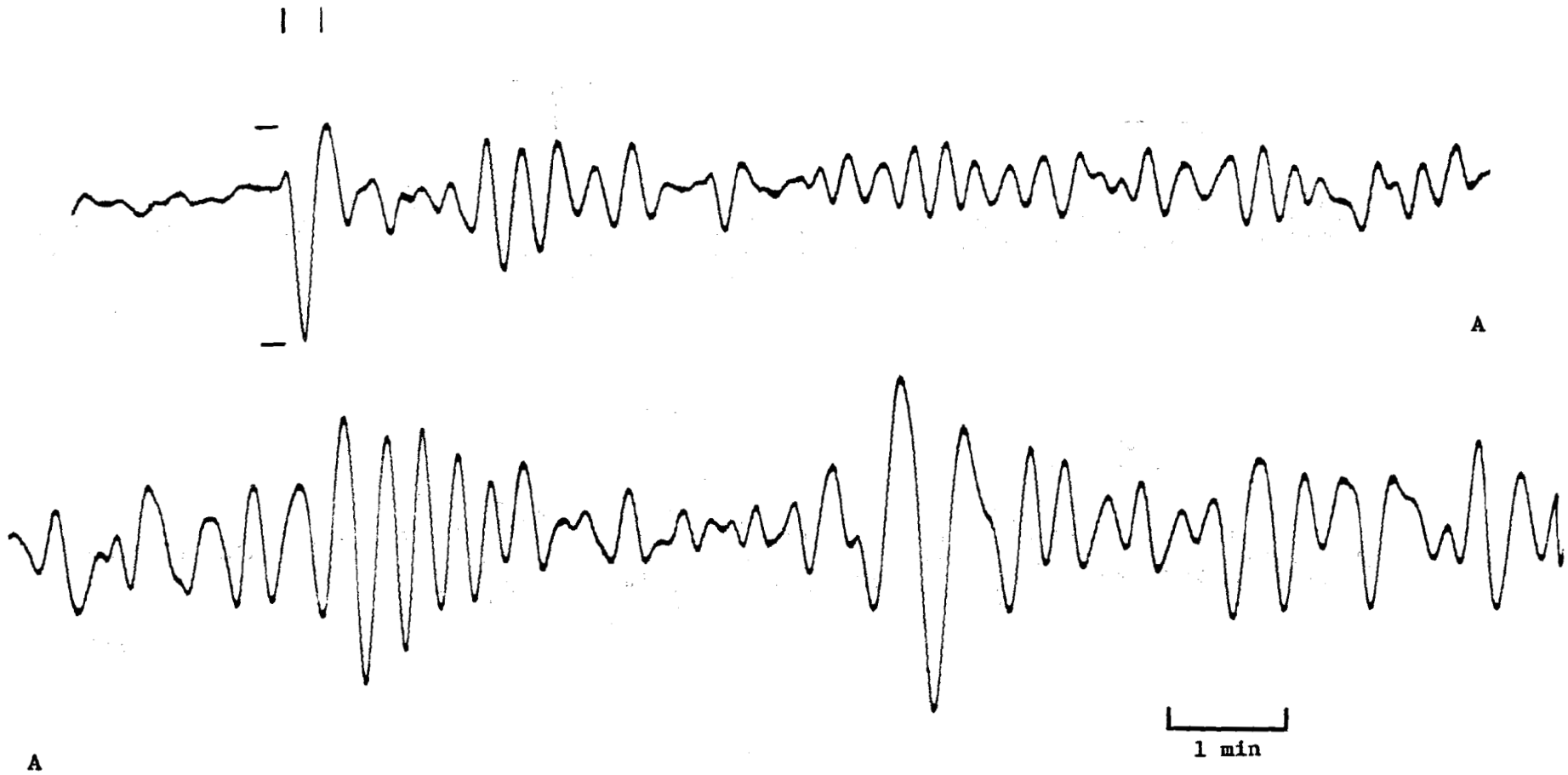
STATION WOL	WIDE BAND
Gain (Replay)	4.1 K
Period, s	10
Amplitude, mμ	1780
Magnitude, m_b	6.15

FIGURE 6. CANNIKIN. LONG PERIOD BODY WAVES (WOL - W/B)



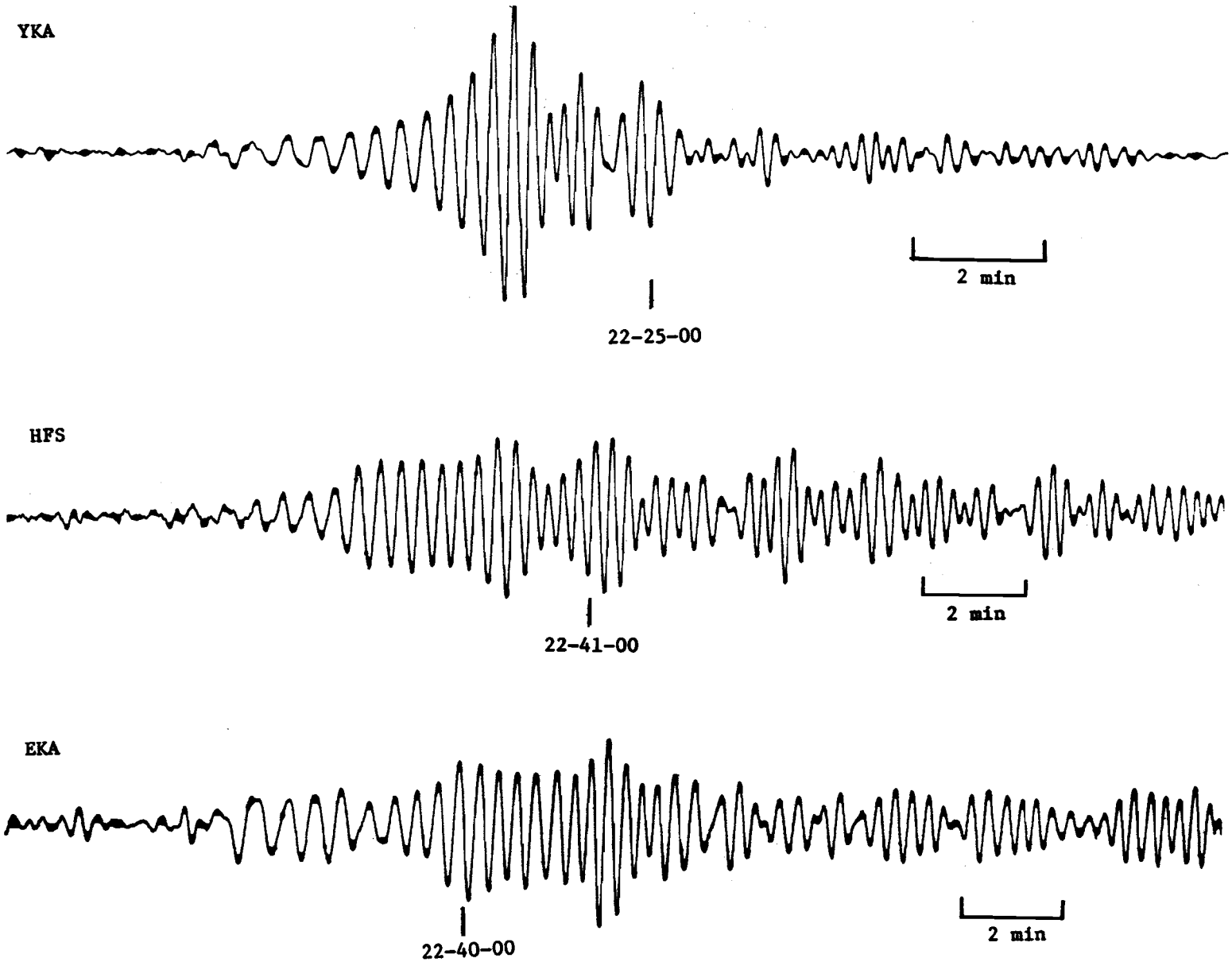
STATION WOL	NARROW BAND
Gain (Replay)	27.6 K
Period, s	19
Amplitude, mμ	250
Magnitude, m_b	5.02

FIGURE 7. CANNIKIN. LONG PERIOD BODY WAVES (WOL - N/B)



STATION	GBA
Gain (Replay)	84 K
Period, s	20
Amplitude, mμ	200
Magnitude, m_b	4.98

FIGURE 8. CANNIKIN. LONG PERIOD BODY WAVES (GBA)


YKA
2 min
22-25-00
HFS
2 min
22-41-00
EKA
2 min
22-40-00

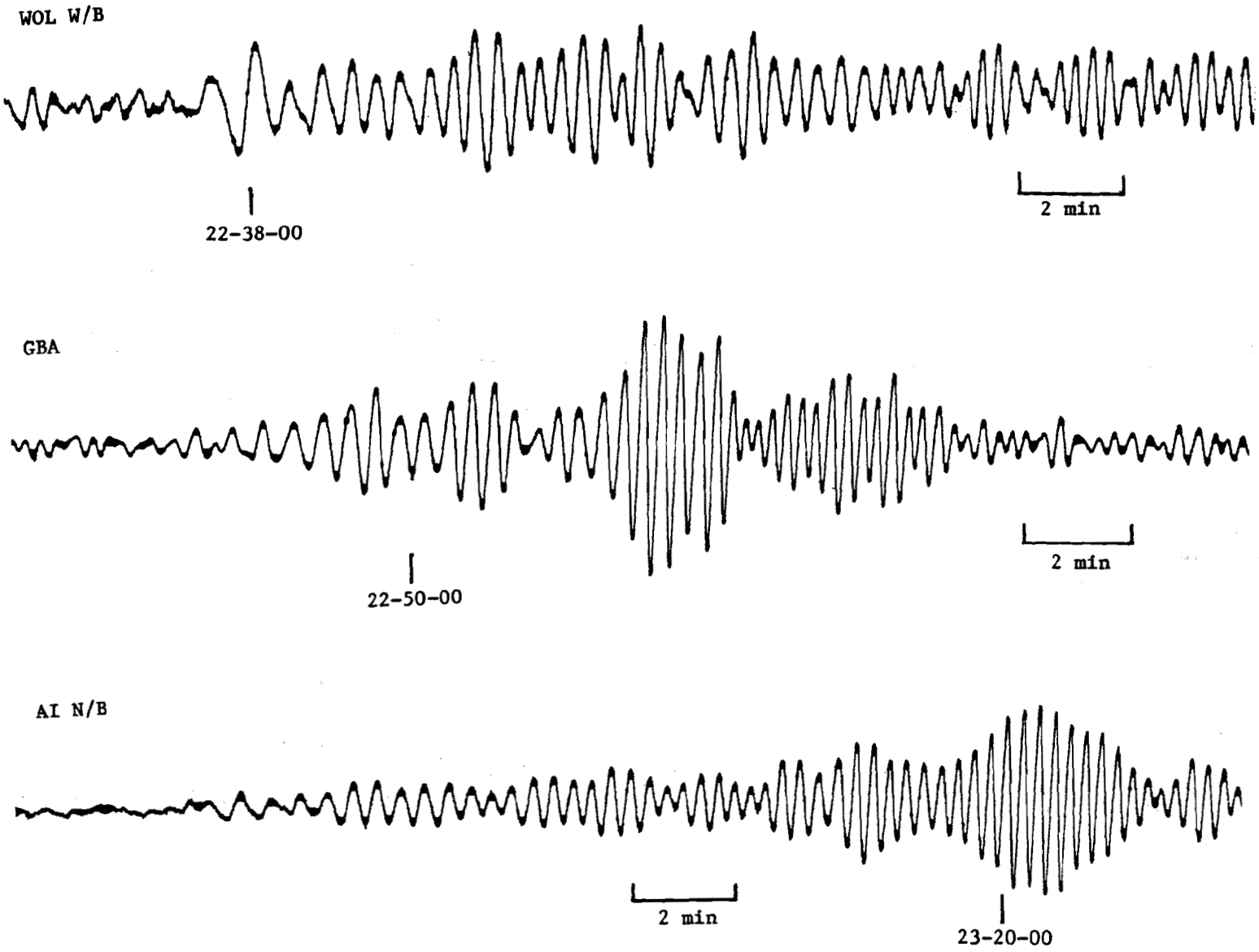


FIGURE 9. CANNIKIN. LONG PERIOD SURFACE WAVES

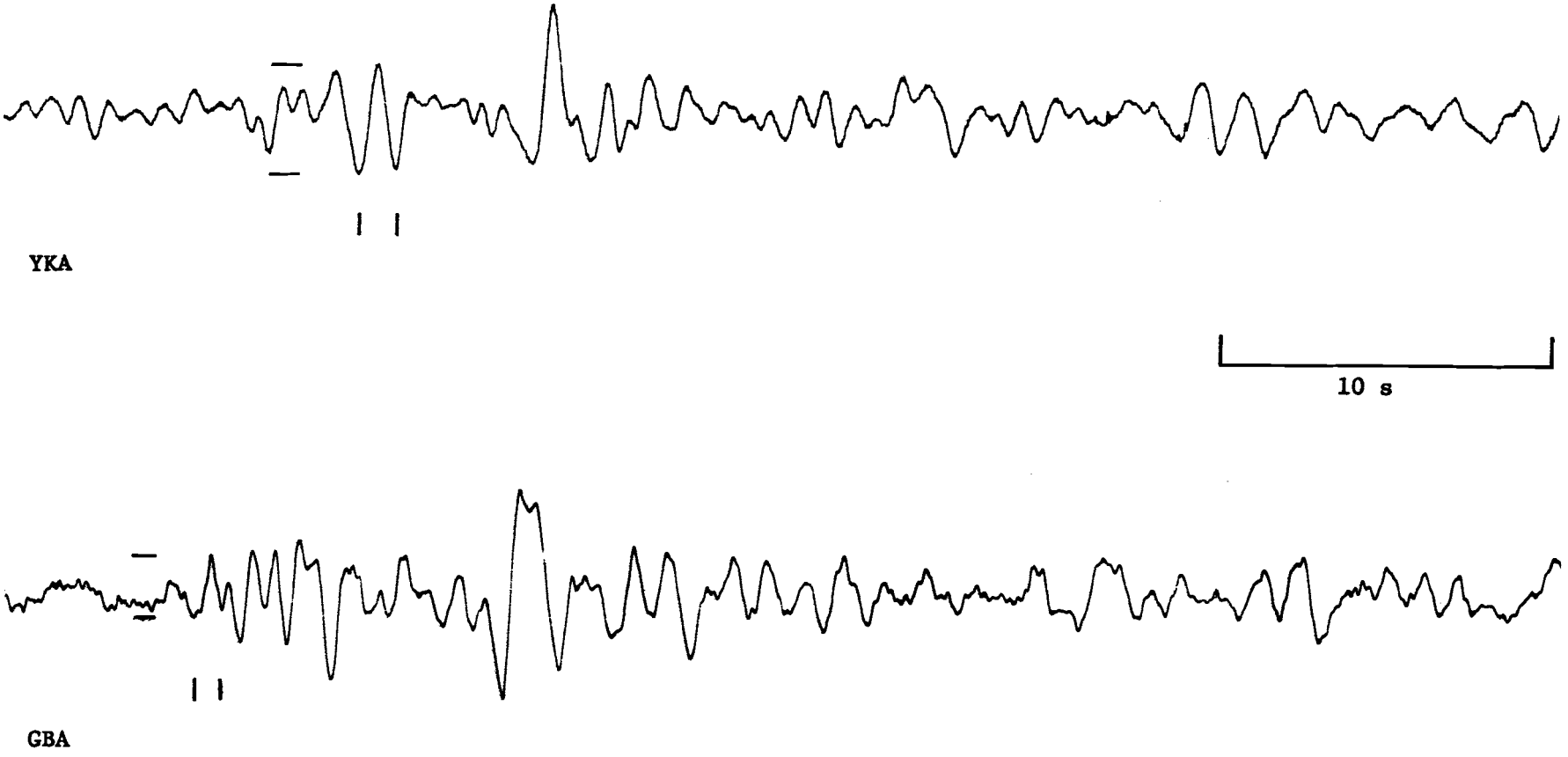


FIGURE 10. CANNIKIN COLLAPSE. SHORT PERIOD BODY WAVES

TABLE 8

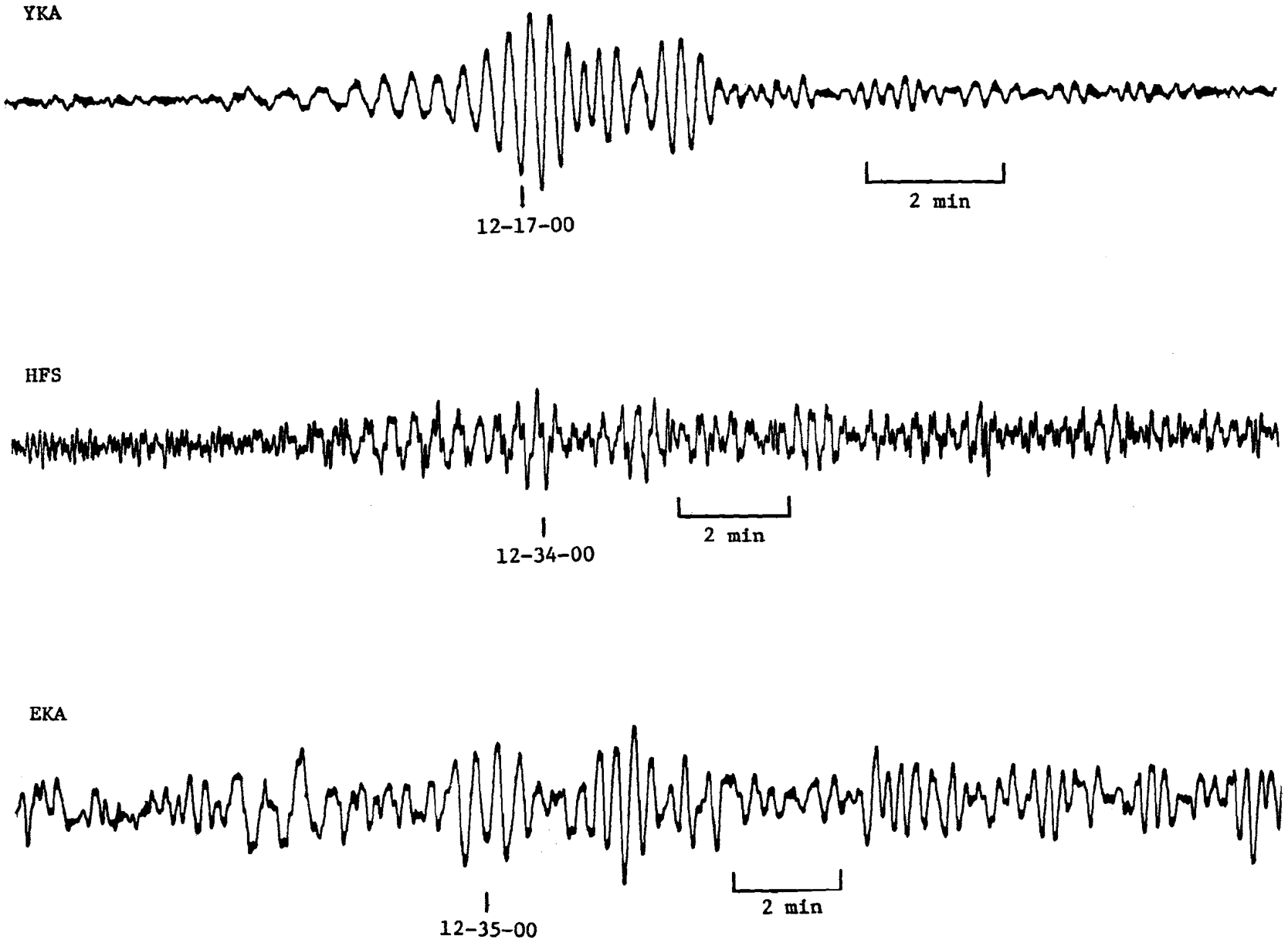
Code name		CANNIKIN COLLAPSE [11]
Date		8 November 1971
Origin time		11 54 12.2 GMT
Site	Latitude	51° 28' 18.7"N
	Longitude	179° 06' 24.3"E
Depth, relative to ground zero		5876 ft (1791 m)
Magnitude	m_b	4.9
	M_s	4.9

TABLE 9

Short Period Body Waves

Station	Onset, h min s	O - C, s	Amplitude, mμ	Period T, s	Magnitude, m_b
YKA	12 01 16.0	- 0.9	16	1.25	4.70
HFS	No short period record				
EKA	Not seen				
WOL	Not seen				
WRA	Not seen				
GBA	12 06 53.7	- 0.4	2	0.85	4.36
AI	No short period record				
				Average m_b	4.53

O = observed onset time.
C = computed onset time [6].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12-17-00
2 min
HFS
12-34-00
2 min
EKA
12-35-00
2 min

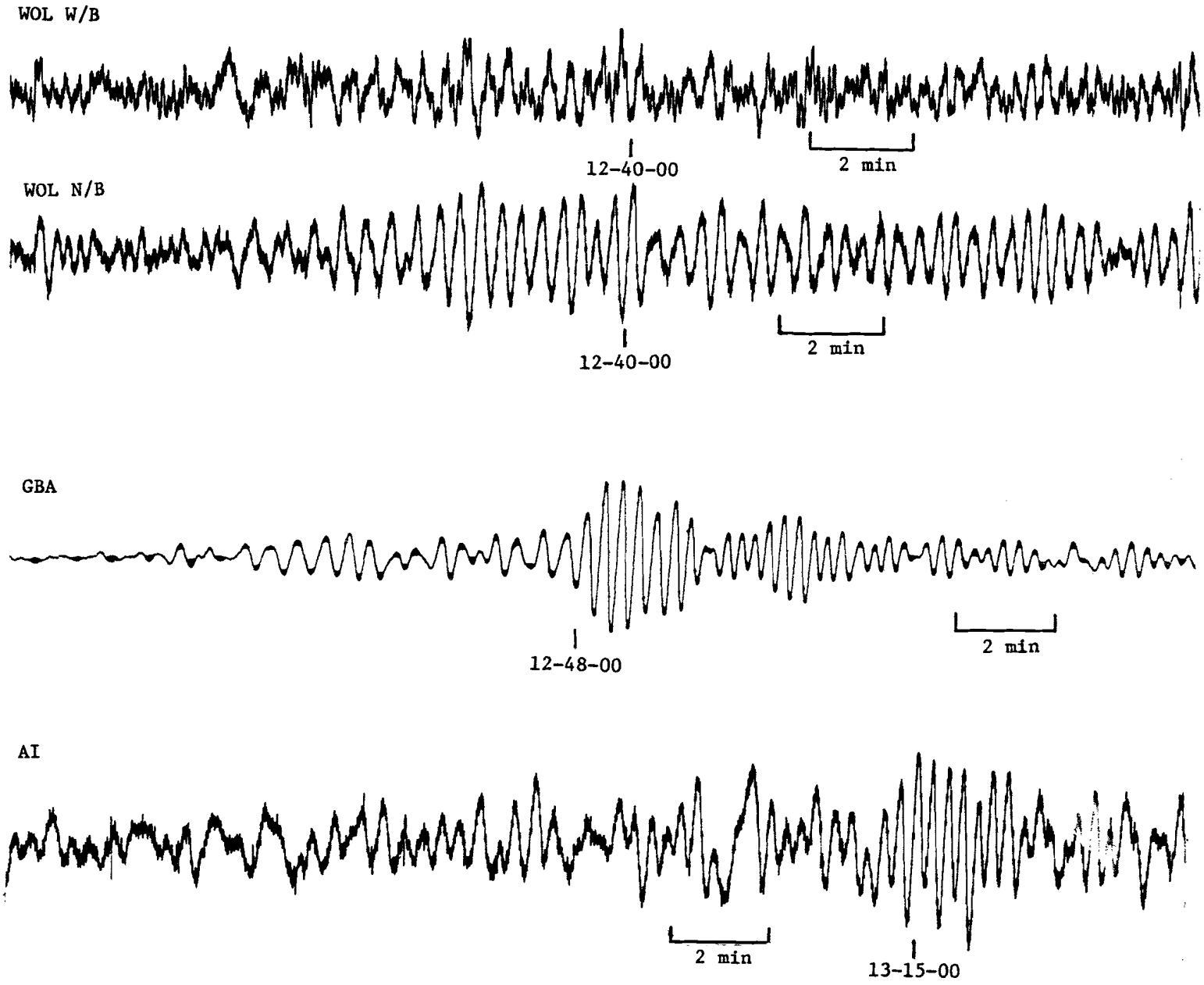

FIGURE 11. CANNIKIN COLLAPSE. LONG PERIOD SURFACE WAVES

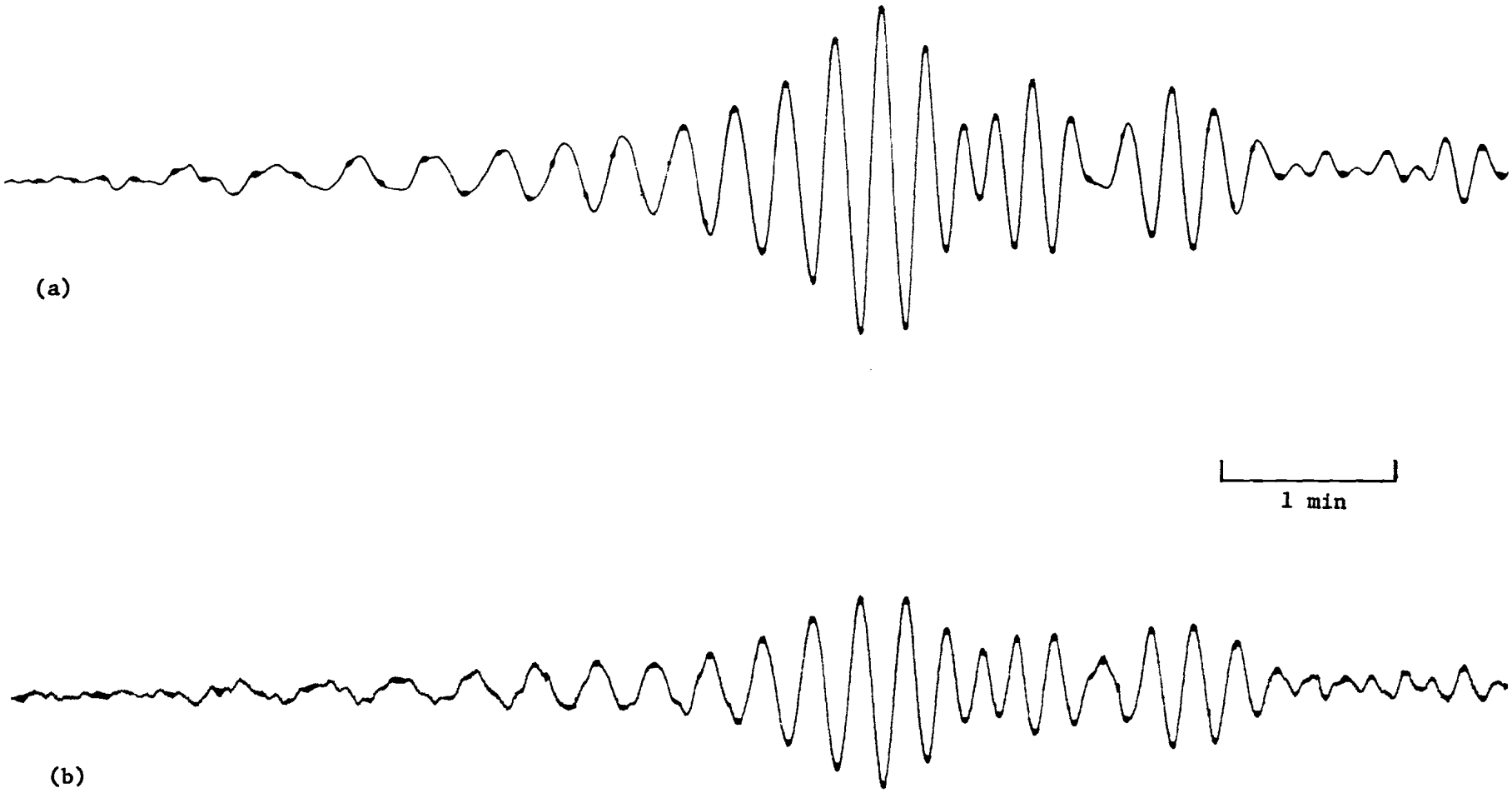

FIGURE 12. SURFACE WAVES AT YKA OF (a) CANNIKIN AND (b) COLLAPSE SHOWING OPPOSITE POLARITY

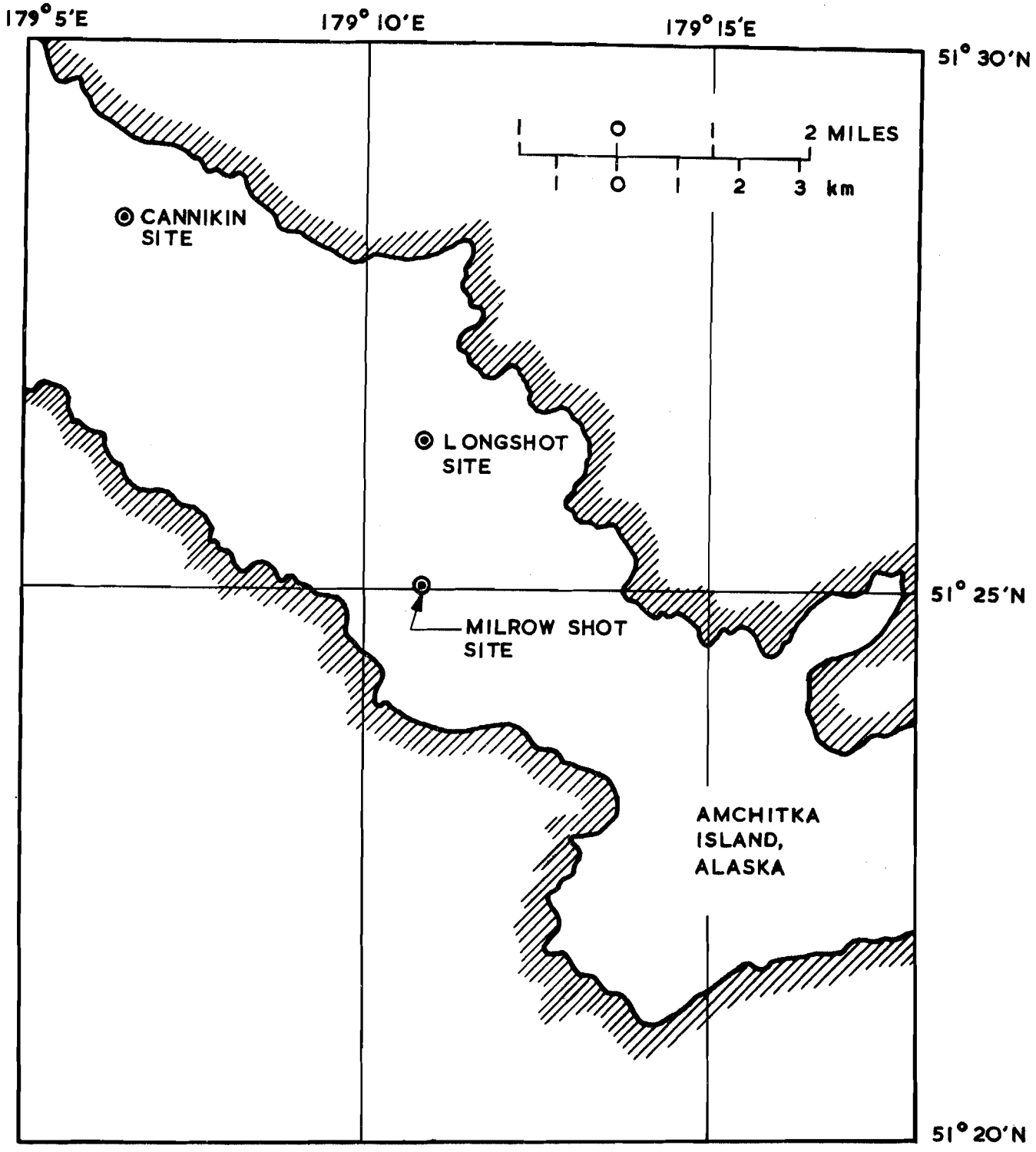

FIGURE 13. AMCHITKA ISLAND SHOWING THE FIRING SITE OF 3 UNDERGROUND NUCLEAR EXPLOSIONS

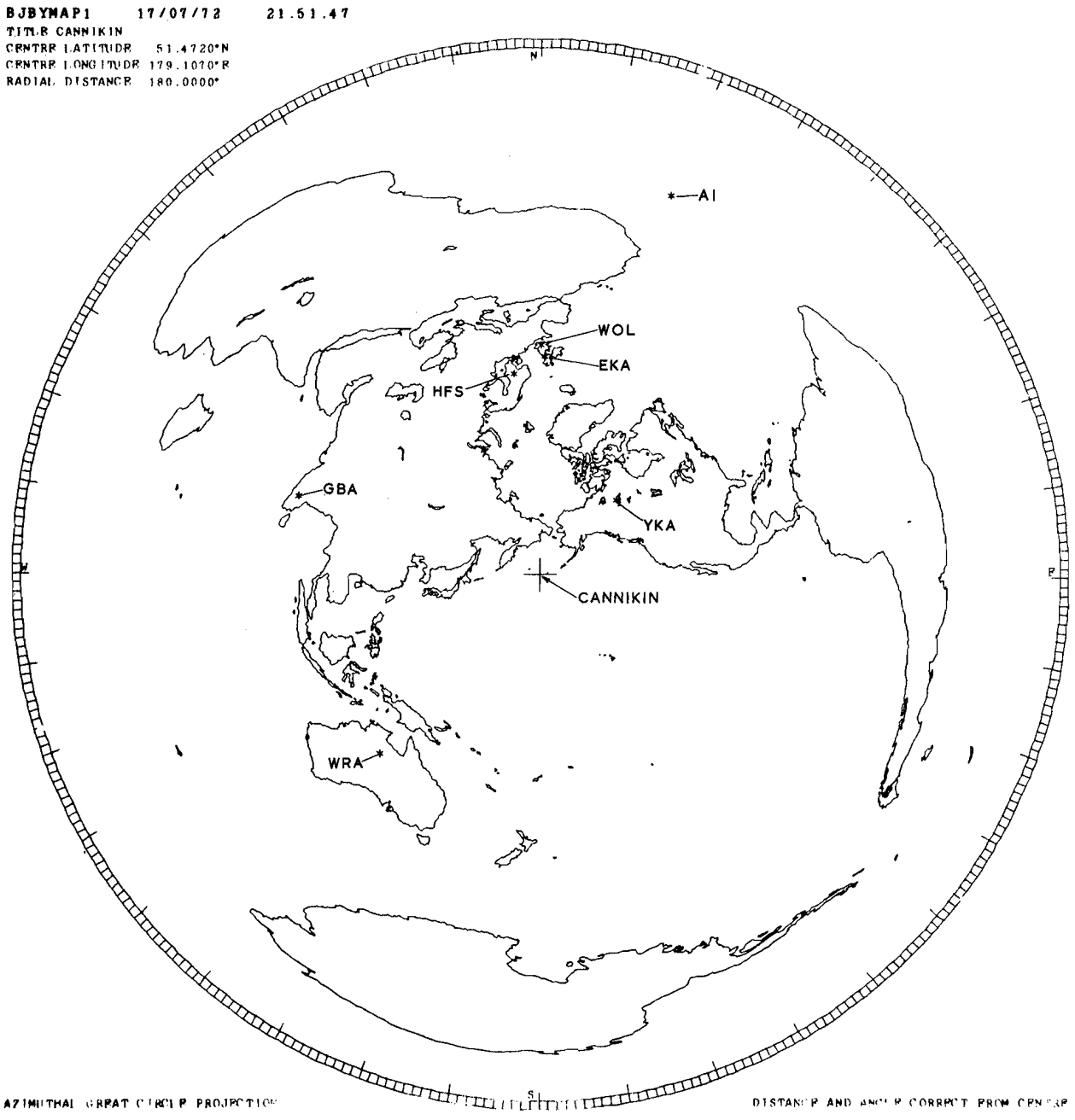

FIGURE 14. EQUIDISTANT AZIMUTHAL GREAT CIRCLE MAP CENTRED ON AMCHITKA SHOWING THE POSITIONS OF RECORDING STATIONS

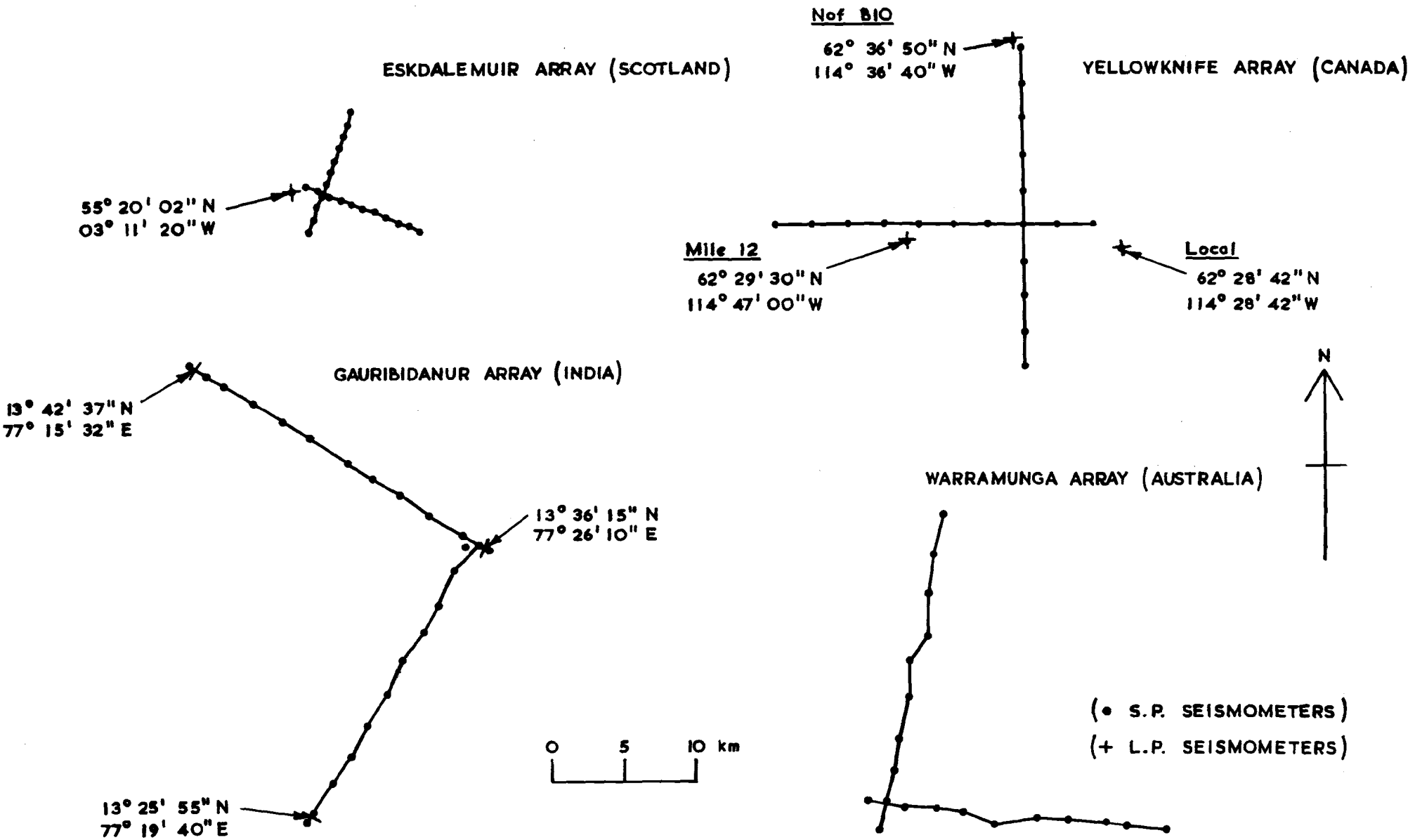

FIGURE 15. PLANS OF THE SHORT PERIOD ARRAYS SHOWING THE LOCATION OF ASSOCIATED LONG PERIOD SEISMOMETERS

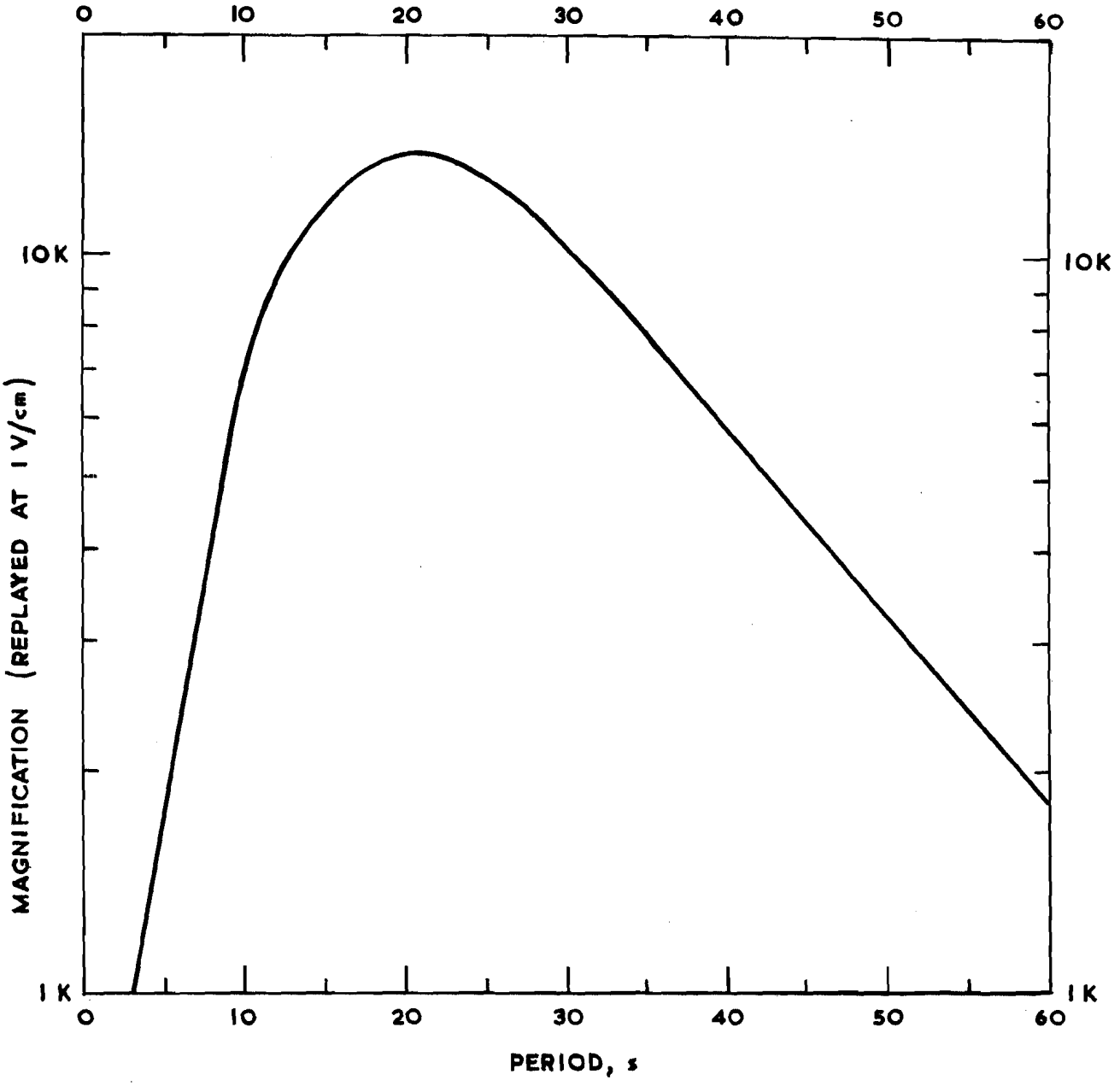

FIGURE 16. THE RESPONSE OF THE YELLOWKNIFE LONG PERIOD ARRAY SEISMOMETERS

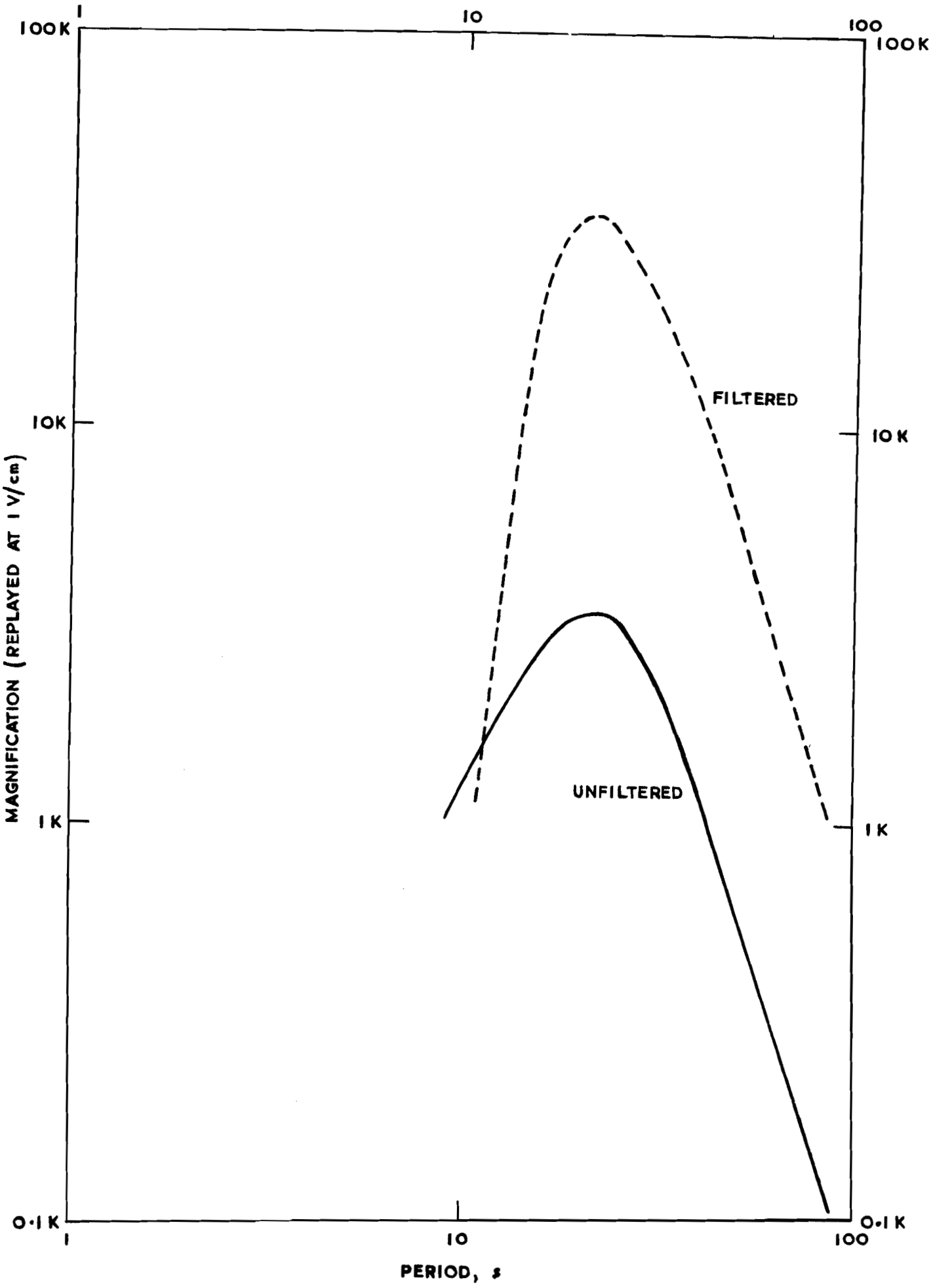

FIGURE 17. THE RESPONSE CURVE OF THE HAGFORS LONG PERIOD ARRAY

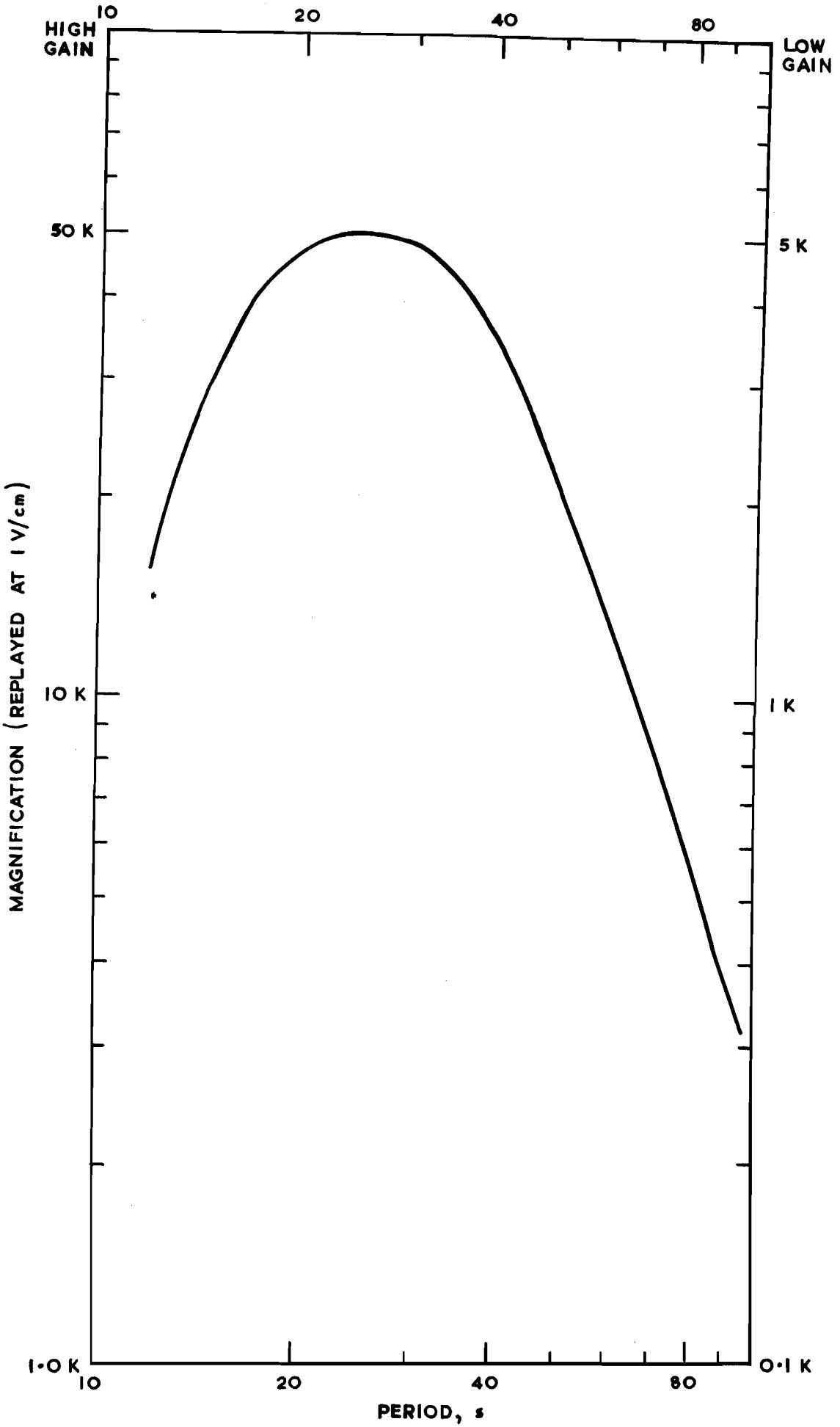

FIGURE 18. RESPONSE OF ESKDALEMUIR LONG PERIOD SYSTEM

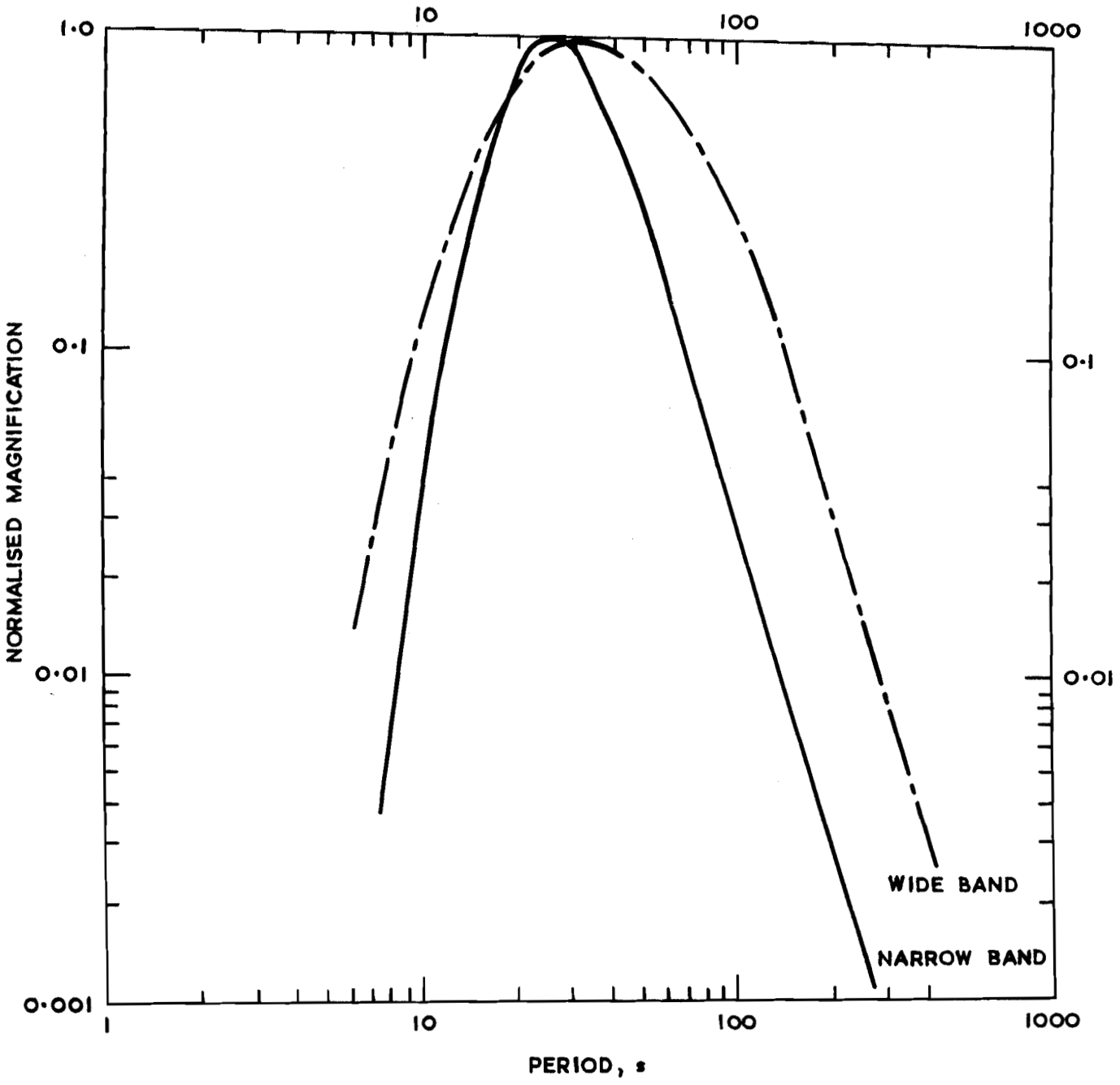

FIGURE 19. WOLVERTON LONG PERIOD SYSTEM RESPONSE

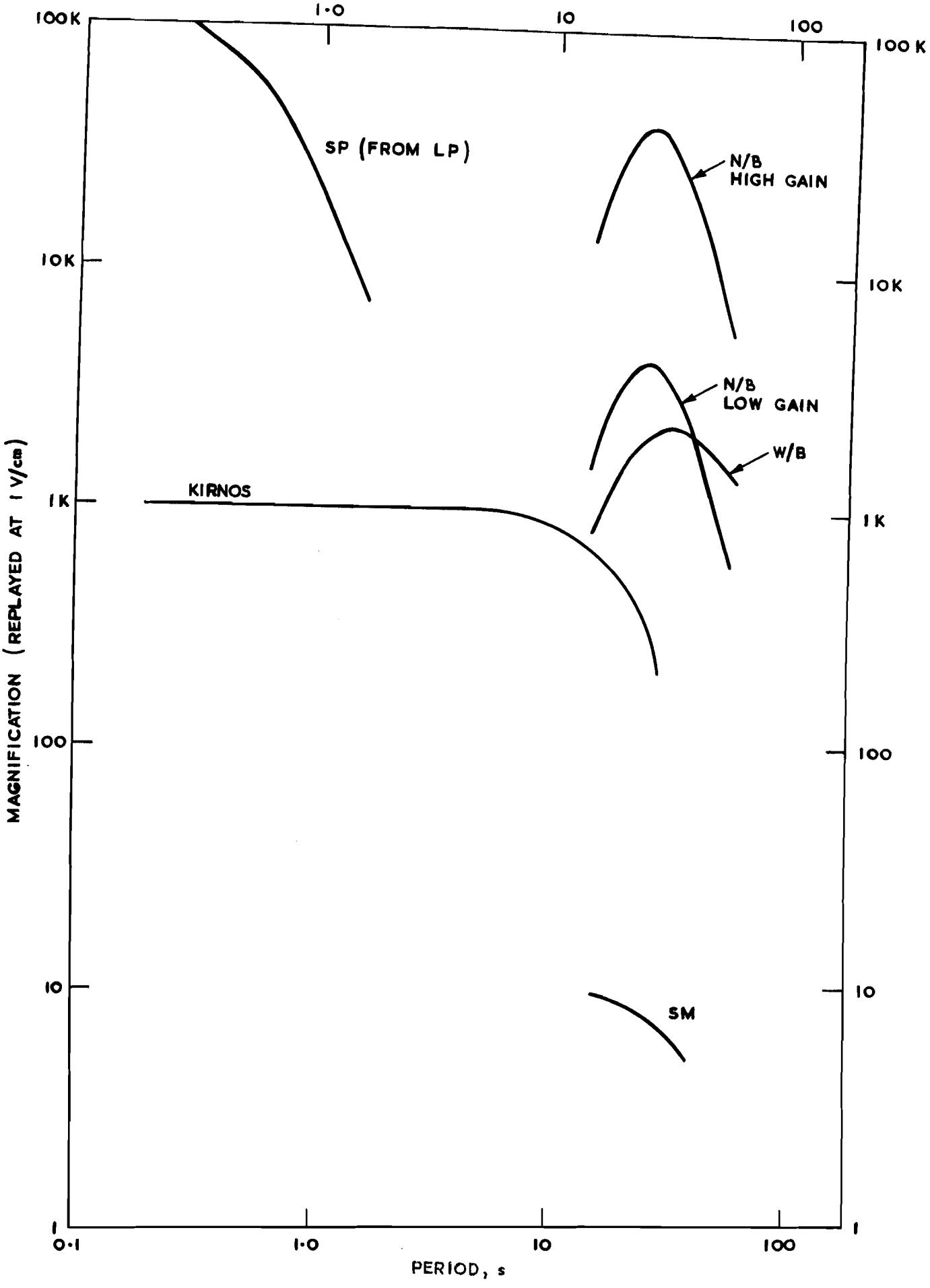

FIGURE 20. RESPONSE CURVES FOR WOLVERTON LONG PERIOD SEISMOMETER AND STRONG MOTION SEISMOMETER

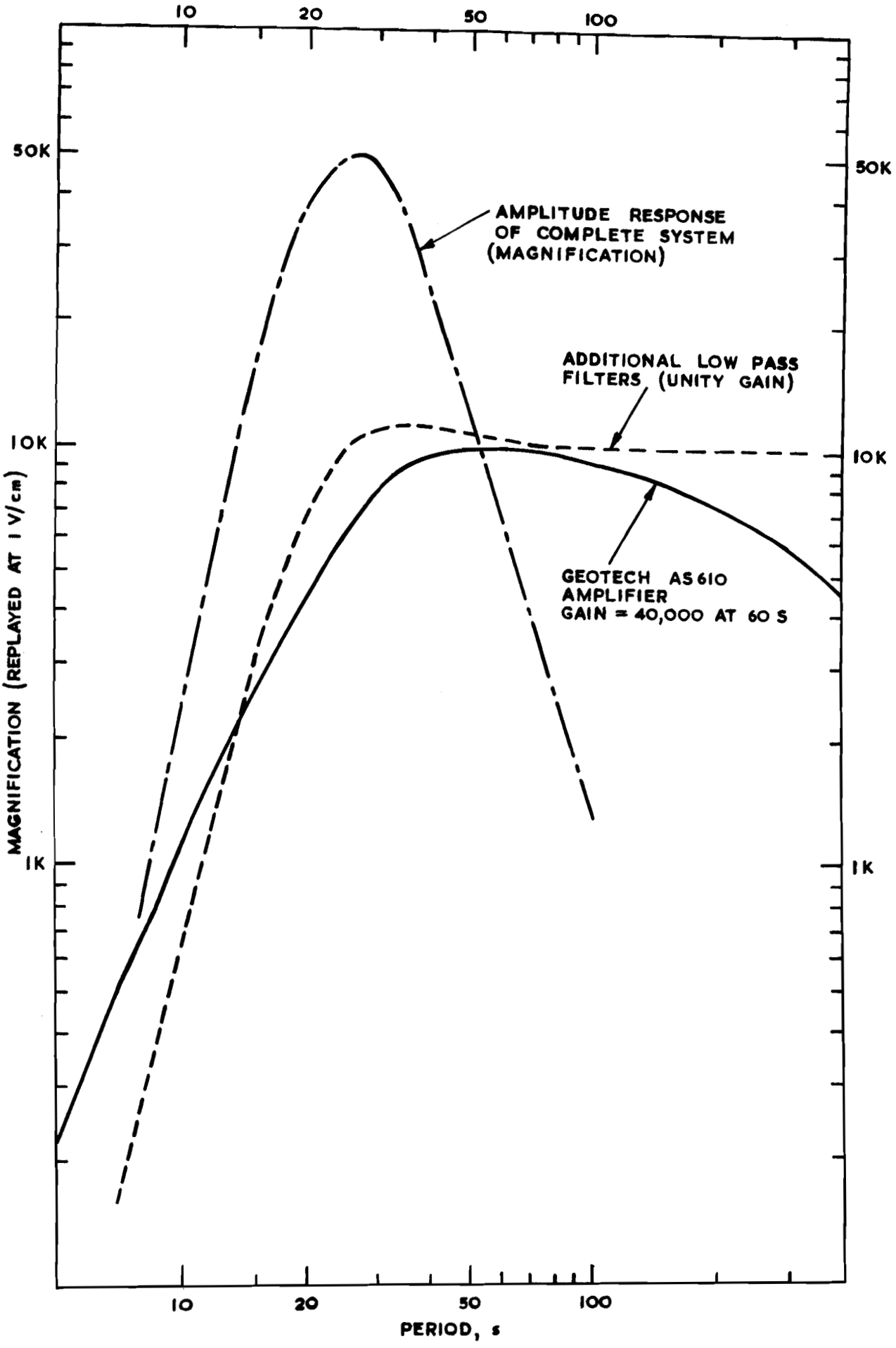

FIGURE 21. FREQUENCY RESPONSES OF COMPONENTS AND COMPLETE SYSTEM AT GAURIBIDANUR LONG PERIOD ARRAY

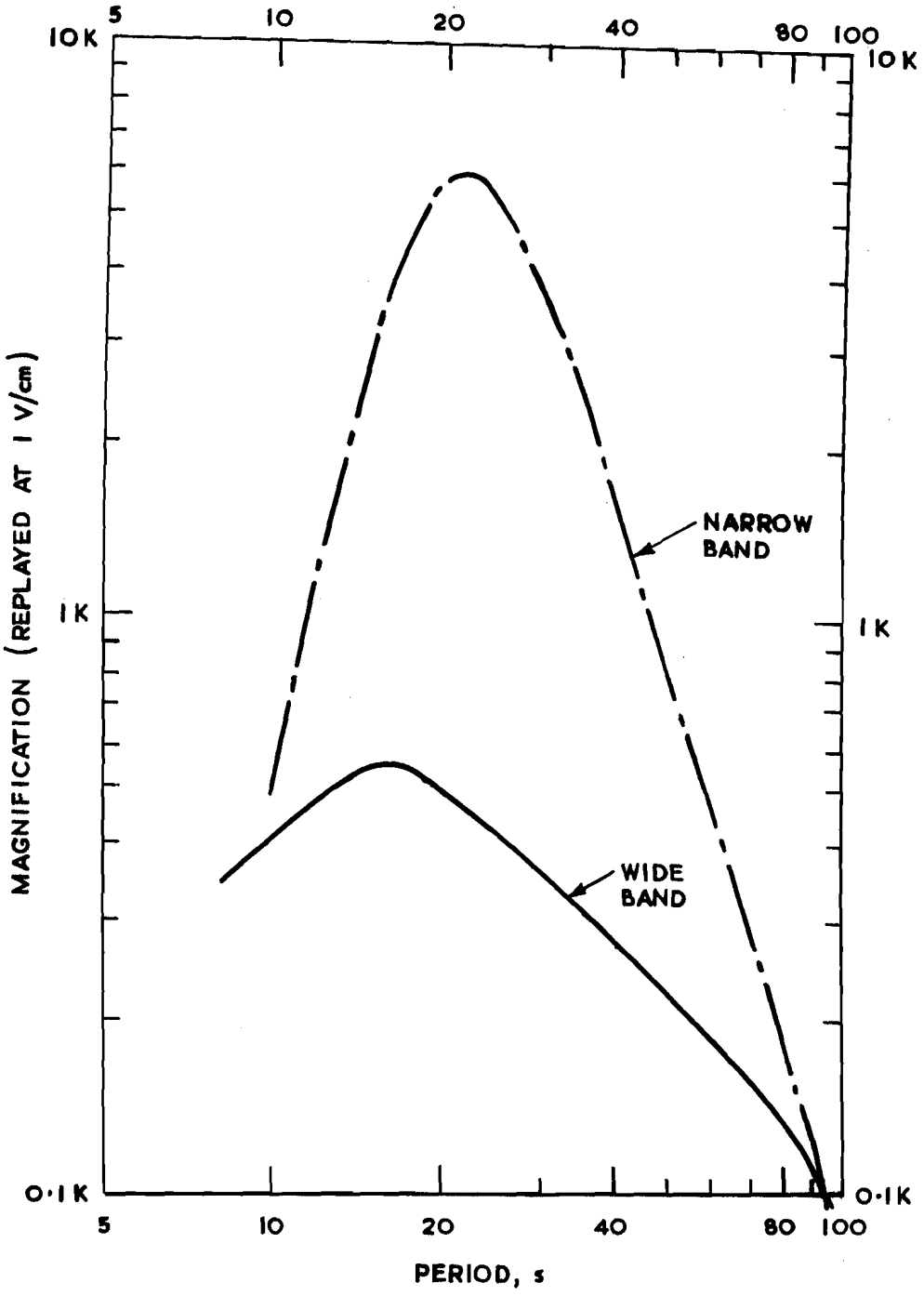

FIGURE 22. AI LONG PERIOD RESPONSE CURVES OF THE PORTABLE SYSTEM USED AT ASCENSION ISLAND